DARPA ADVANCEMENTS PROVIDE ALTERNATIVE ENERGY AND POWER

By Scott R. Gourley

One of DARPA's key core technology areas focuses on power and energy, and addresses portable sources of compact electric power that are critical for emerging network-centric operations. Within this arena, DARPA has placed considerable emphasis on the development of new technologies that will not only reduce soldiers' logistics burden, but also help reduce the military's current reliance on petroleum-based power supplies to power its ground systems, aircraft, and non-nuclear ships.

Examples of DARPA's new technology explorations can be found in its programs like Mobile Integrated Sustainable Energy Recovery (MISER), Palm Power, BioFuels, Very High Efficiency Solar Cell (VHESC), and High Energy Distributed Lighting (HEDLight).

MISER

According to Dr. Valerie M. Browning, former program manager at DARPA, the MISER program was originally the vision of an earlier DARPA program manager named Rosemary Szostak.

"She was a chemist who spent a lot of her time thinking about what happens in the future military if petroleum fuels are no longer an option," Browning explained. "What might the military look like? How might it execute its missions?"

She noted that MISER, currently led by Program Manager Khine Latt, was one of the activities emerging from that thinking, in the sense that one of the underlying considerations had been how the military could enable its deployed forces, particularly those who might be operating in unfriendly environments, to be more self-sufficient.

"So the idea of the MISER program was to take waste, which is something that is generated in the field and has to be dealt with in the field, and be able to convert it into usable fuel for the generators already in place," she said.

"Early on, in the formulation phase, one of the things that came to light was that it really was not the right time to try and go from waste to fuel in the field. We can certainly do that at fixed installations and large-scale plants today. But in terms of trying to make something that could be deployable and useful in the field, it wasn't the right time. However, what did seem to be doable was coming up with a program that would enable waste to be converted to electricity. And that was the program that she started in 2004.

"Although the primary goal was waste to electricity, they didn't completely lose sight of the waste-to-fuel concept," she added. "They did have one effort that was trying to develop a plastic that could be used for packaging and that could be more readily broken down into a fuel. And that still remains something of a far-term vision for the program. It's a chemistry problem right now, so they are trying to develop the packaging materials of the future. Assuming that the other technologies become more deployable and more readily brought to the idea of generating the fuel, they would already have

Below, left: Dr. Douglas Kirkpatrick, program manager of the DARPA BioFuels program. Below, right: The DARPA BioFuels program seeks to use renewable feedstocks to generate an affordable, alternative source for JP-8 jet fuel. The biofuels cycle, from feedstocks to jet fuel, is depicted here.

Courtesy of DARPA

the higher energy content and more easily broken down plastics that could be used as tactical packaging. And they are looking to not only make this material to be readily degradable into a fuel, but also to actually make it from agricultural waste to begin with."

Browning said that other investigations conducted under the MISER program included a project "that uses a supercritical water depolymerization, basically. It's a generator that works on high-temperature, high-pressure water to convert plastics into a gas. And the steam from that gas can then be used to run a generator that produces electricity."

She noted that Phase 1 efforts were conducted by General Atomics, and included demonstration of a 5 kilowatt (kW) pilot plant.

"The current Phase 2 goal is to extend that up to 60 kW," she added. "And they also want to extend it out to include the ability to put in paper and food as well as plastic."

Another project funded under the MISER effort involved exploration of a fuel cell that would run directly on waste products.

"The company there is CellTech," Browning explained. "And what ended up happening was that there is a lot of stuff in waste that, from a fuel-cell perspective, just can't be converted to fuel. And the remaining 'gunk' was fouling up the fuel-cell 'innards' and compromising lifetime of the cell. But along the way, they realized that the type of fuel cell they were looking at would be amenable to running directly on JP-8, which is the preferred military logistics fuel. It's basically kerosene but it's got a lot of other 'gunk,' like sulfur, in it. And because it has all of these other components in there, it's not a fuel that you can pour into state-of-the-art fuel cells. However, the fuel-cell approach that was being developed under MISER looks to be a promising approach for just pouring JP-8 in and getting electricity out."

Based on its potential, the project was recently pulled out of the MISER umbrella and

DARPA's Very High Efficiency Solar Cell (VHESC) program targets the development of more efficient solar cells for use as battery-charging modules in soldiers' tactical electronic devices.

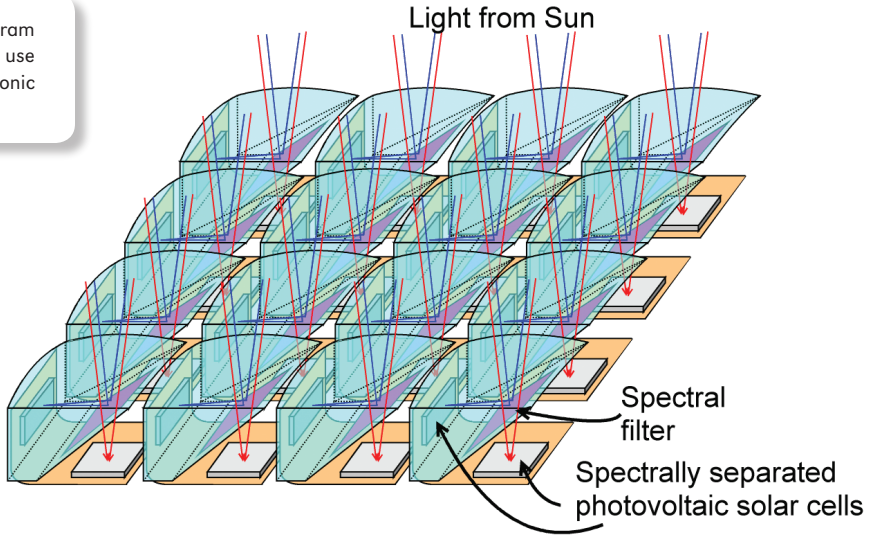

Image courtesy of DARPA

is being continued as a separate JP-8 fuel-cell exploration effort.

PALM POWER

Browning inherited responsibility for DARPA's Palm Power program in 2002.

"At the time, there were probably eight or nine different approaches we were looking at with the idea that the time was right to start thinking about new approaches that would provide a power-generation solution that looks, feels, and performs like a battery already being used except that it would last a lot longer," she said.

Significantly longer life for the new power source would mean that soldiers would carry fewer batteries, with resulting improvement in tactical load burdens.

"We wanted to come up with a solution that would be seamless to the user in terms of being able to work their equipment but greatly reduce the amount of weight they would have to shoulder in terms of providing the electricity to that equipment," she said. "But if you want a battery that looks the same but lasts 10 times longer, there just isn't any chemistry out there that will do it. And unless you want to reinvent the periodic table, there's nothing on the horizon that would give you that kind of breakthrough in performance."

So DARPA efforts instead focused on alternative methods for generating electricity.

"We went away from a battery, which you have to view as 'a bucket of electricity,' to a generator that would convert a fuel into electricity. So you can always pour more fuel in. And, in terms of efficient storage of energy, a liquid fuel is much better than a battery," Browning observed, adding that these Palm Power investigations led to milestones that included the first demonstration of a fully packaged, direct methanol fuel concept.

After studying what Browning called "the entire landscape of potential solutions," and combining that focus with knowledge gained from other recent technology efforts, the program made some "down select" decisions regarding technologies.

"The short version of the Palm Power program is that we were successful in demonstrating [a] solid oxide fuel cell in a portable device and it did demonstrate, depending on how you planned on using it, a seven to eight factor of improvement in energy density," she said.

Following that proof of concept, DARPA has engaged the U.S. Army, U.S. Air Force, and U.S. Special Operations Command in a transition program called the Robust Portable Power System.

"It's taking the most promising technologies that came out of the Palm Power program and moving them into an application demonstration," Browning said.

Reflecting on the significance of these efforts to warfighters, she observed, "We're trying to minimize the logistics burden, making them more efficient and more capable without having to carry as much in terms of batteries for the systems they are using."

BIOFUELS

Many of the key DARPA efforts to reduce the military's current reliance on petroleum-based power supplies are taking place under the BioFuels program.

"BioFuels is focused on creating an affordable alternative JP-8 source from renewable feedstocks," explains Program Manager Dr. Douglas Kirkpatrick. "The focus is not on creating fuel that doesn't meet JP-8 standards but somehow we convince someone to take it and use it anyway, but rather on creating a fuel from bio feedstocks that is chemically and engineering-wise indistinguishable from JP-8. We want to make JP-8 from something other than oil, but in any way you would ever measure it, it would be JP-8."

DARPA's initial focus was in the creation of that product from agricultural or aquacultural oils. Although efforts included triglyceride oils like canola or soy, particular attention was placed on oils not used in the food industry, including jatropha oil and algae oil.

"The benefit of that effort is that you have the potential to create a fairly substantial feedstock train that is non-competitive with food stocks," Kirkpatrick said. "You don't want to run into an issue like they are running into now on the ethanol side of the house, where people are growing corn to produce ethanol and it has become something of a competition to corn grown for food. Nobody wins."

The BioFuels program idea of taking materials not commonly used is further enhanced through the possibility of growing those materials on land not usable by agricultural food-crop stocks.

"The program has been under way for less than a year and we have had some astounding successes already," Kirkpatrick noted. "In the

Prototype HEDLights have been installed on the USS *Wasp*, the USS *Chafee*, and the USS *Pearl Harbor* (pictured above). The HEDLight technology has proved to be both more efficient and more reliable than other forms of lighting.

Photo courtesy of Fiberstars

past few months, we have had two prototype fuels tested that meet key first-level JP-8 specifications. And affordability is such that we anticipate that the cost in production will be less than $3 per gallon.

"So it has succeeded in a fashion that is certainly getting all of our attention," he added. "And we are in the process now of expanding that program to go after not only the triglyceride oil feedstocks, but also feedstocks that would comprise simple cellulosic materials as well as technology to really drive the affordability of algae feedstock, so that algae can be an affordable large-scale feedstock source as well.

"Right now we're working at liter-scale quantities," he acknowledged. "And there's a fairly substantial cost in scaling this up to a pilot plant that would be able to produce hundreds of thousands of gallons per year, which you would use to validate it in various applications. But the benefit we are seeing is that, even at that pilot scale, the production costs may already be down to $3.50 per gallon or less."

VERY HIGH EFFICIENCY SOLAR CELL

DARPA's Very High Efficiency Solar Cell (VHESC) program targets the development of photovoltaic devices with efficiencies significantly greater than those found today.

"Today's top-of-the-line/state-of-the-art silicon solar cells are about 20 percent efficient," Kirkpatrick said. "The more common stuff that you will buy at large scale is between 14 and 15 percent. And what they call 'low-cost' solar cells – so-called 'thin-film' solar cells – are typically around 10 percent.

"The problem for us in the DoD [Department of Defense] is that often the area over which we apply a solar cell, particularly for portable devices, is tremendously constrained. And it's not really easy for us to take something and fold it out to collect a lot of solar energy."

Drawing size parallels with the solar-powered calculators found in many homes, he said, "If I wanted to do that for a radio and I wanted to use just the surface area of the device for that solar cell then that solar cell has got to climb in its efficiency – and it's got to climb a lot. The numbers that typically get bandied about are 40 to 50 percent efficiency. And that's precisely what we are doing in the Very High Efficiency Solar Cell program: pursuing the development of 50 percent efficient solar-cell modules for near-term application as a battery charging module in tactical electronic devices for the soldier."

Program participants expect to have their first 40 percent efficient module prototypes by the summer of 2008, with the first 50 percent efficient modules following 18 to 24 months after that.

"At this point in time people involved with the program would tell you that achieving 50 percent efficiency is a foregone conclusion," he said. "We can do 50 percent. We know how to do it now. It's just a matter of time. So the other two key metrics that we're now going after are $1,000-per-square-meter production cost – putting you at $2 per watt, and we may get well underneath that as well – and a production capacity/manufacturing process that is scalable to a square meter per second. For comparison, that's the rate at which we print newspapers.

Close-up of a component of an HED lighting system as installed aboard a U.S. Navy ship.

"That's important because if we are ultimately going to make a dent, if it is going to be commercially realizable, then we have to do that at a *scale* that actually matters," he added.

An early DARPA test prototype integrated the first stage of the VHESC system into the battery on the Defense Advanced GPS Receiver (DAGR). Within one hour, the prototype cell recharges the battery that gives DAGR 24 hours of operation.

Summarizing VHESC, Kirkpatrick concluded, "So, in the future, the soldier, in general, can deploy with just two batteries: one that is outside the device that can be recharged in an hour; and one that is in the device. And that's all they have to carry."

HEDLIGHT

Another DARPA program currently exploring related power and energy technology boundaries is the High Efficiency Distributed Lighting program, or HEDLight.

Referring to his own pre-DARPA background in the lighting industry, Kirkpatrick explained, "I knew that there were a lot of technologies that were, if you will, 'sitting on the shelf.' They would eventually come out, but there was no commercial driver to 'pay the money to buy down the risks' at that point in time. But within the DoD, there were fairly compelling reasons to push those technologies out the door."

The HEDLight technology recognizes that when light bulbs are put into a fixture you have an integrated device. It's not about efficiencies of the ballast, bulb, or fixture. Rather it is the efficiency of all of those items in combination.

Kirkpatrick related a scenario common to both military ships and many commercial hotel atriums, in which there is a cost associated with the immediate – and critical – replacement of burned-out lighting.

He explained that HEDLight technology uses a combination of LEDs as well as some advanced discharge lighting to deliver the light using plastic optical light pipes, and achieving one of two effects: rendering the light very easily packaged with a quantum leap in life expectancy; or relocating the lights to deliver superior lighting projected up through plastic light pipes from easily accessible fixtures.

To date, the prototype HEDLights have been installed on the USS *Wasp* (LHD 1), USS *Pearl Harbor* (LSD 52) and, most recently, USS *Chafee* (DDG 90).

"They have been on the *Pearl Harbor* now for about six months in the well deck area, which is one of the most aggressive environments because it's open to the sea, and they haven't had a failure," he said, adding that technology from the now-completed program is also available commercially.

Courtesy of DARPA